ASPRS Positional Accuracy Standards for Digital Geospatial Data

Edition 2. Version 1.0-August 2023

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CSRC Fall Meeting 2023

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Mapping Standards

YEAR	STANDARD
1947	National Map Accuracy Standards
1990	ASPRS Accuracy Standards for Large Scale Maps
2004	ASPRS Guidelines Vertical Accuracy Reporting for LiDAR Data
2014	ASPRS Positional Accuracy Standards for Digital Geospatial Data Edition1, Version 1.0, Nov 2014
2023	ASPRS Positional Accuracy Standards for Digital Geospatial Data Edition1, Version 1.0, August 2023

Why?

☐ Users expressed concerns and suggested revisions based on their experience applying the standards in real-world situations.

☐ Technologies have evolved in such a way as to challenge the assumptions made in ASPRS Standards 2014.

Summary of Changes

- Eliminated references to the 95% confidence level as an accuracy measure.

Why?

Use of both RMSE and the 95% confidence level leads to confusion and misinterpretation.

Now:

The RMSE is a reliable statistical term that is sufficient to express product accuracy, and it is well understood by users.

- Relaxed the accuracy requirement for ground control and checkpoints.

Why?

With goals for final product accuracies approaching a few cm in both the horizontal and vertical, it becomes difficult, if not impossible, to use RTK methods for control and checkpoint surveys, introducing a significant burden of cost for many high-accuracy projects.

Now:

If best practices are followed, safety factors of three and four times the intended product accuracy are no longer needed.

- Required the inclusion of survey checkpoint accuracy when computing the accuracy of the final product.

Why?

Since checkpoints will no longer need to meet the three-times-intended-product accuracy requirement, the error in the checkpoints survey may no longer be ignored when reporting the final product accuracy.

Now:

Uncertainty associated with the checkpoints is factored in.

- Removed the pass/fail requirement for Vegetated Vertical Accuracy (VVA) for lidar data.

Why?

Data producers and data users have reported that they are challenged in situations where Non-Vegetated Vertical Accuracy (NVA) is well within contract specifications, but Vegetated Vertical Accuracy (VVA) is not.

Now:

Only NVA should be used when making a pass/fail decision for the overall project. VVA should be evaluated and reported but should not be used as a criterion for acceptance.

- Increased the minimum number of checkpoints required for product accuracy assessment from 20 to 30.

Why?

20 checkpoint requirement is not based on rigorous science or statistical theory; rather, it is a holdover from legacy standards.

Now:

According to the Central Limit Theorem, regardless of the distribution of the population, if the sample size is sufficiently large ($n \geq 30$), the sample mean is approximately normally distributed, and the normal probability model can be used.

- Limited the maximum number of checkpoints for large projects to 120.

Why?

Based on statistical theory, there is insufficient evidence for the need to increase the number of checkpoints indefinitely as the project area increases.

Now:

The maximum number of checkpoints is 120.

- Introduced a new accuracy term: “three-dimensional positional accuracy."

Why?

Three-dimensional (3D) models require consideration of 3D accuracy, rather than separate horizontal and vertical accuracies.

Now:

Many future geospatial data sets will be in true 3D form; therefore, a method for assessing positional accuracy of a point or feature within the 3D model is needed to support future innovation and product specifications such as 3D city modeling and oblique photogrammetry.

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Specific Requirements

Accuracy testing is always recommended but may not be required for all data sets; specific requirements must be addressed in the project specifications. When testing is required:

- Horizontal accuracy
  - shall be tested by comparing the planimetric coordinates of <u>well-defined points</u> in the data set with coordinates determined from an independent source of higher accuracy.
- Vertical accuracy
  - shall be tested by comparing the <u>elevations of the surface</u> represented by the data set with elevations determined from an independent source of higher accuracy.

- 3D accuracy
  - shall be tested by comparing the X, Y, and Z coordinates of well-defined points in the data set with X, Y, and Z coordinates determined from an independent source of higher accuracy.

  - Ground control accuracies and survey procedures should be established according to project requirements.

Statistical Assessment of Accuracy

- Horizontal accuracy:
  - is to be expressed as $RMSE_H$, derived from two horizontal error components, $RMSE_X$ and $RMSE_Y$.
  - Vertical accuracy
    - is to be expressed as $RMSE_V$.
  - Three-dimensional positional accuracy
    - is to be expressed as $RMSE_{3D}$, derived from horizontal and vertical accuracy component, $RMSE_H$ and $RMSE_V$.
- Furthermore, elevation data sets shall also be assessed for horizontal accuracy ($RMSE_H$) whenever possible.

Systematic Error and Mean Error Assumptions

- Except for vertical data in vegetated terrain, the assessment methods outlined in these Standards assume that the data set errors are normally distributed and that any significant systematic errors or biases have been removed.

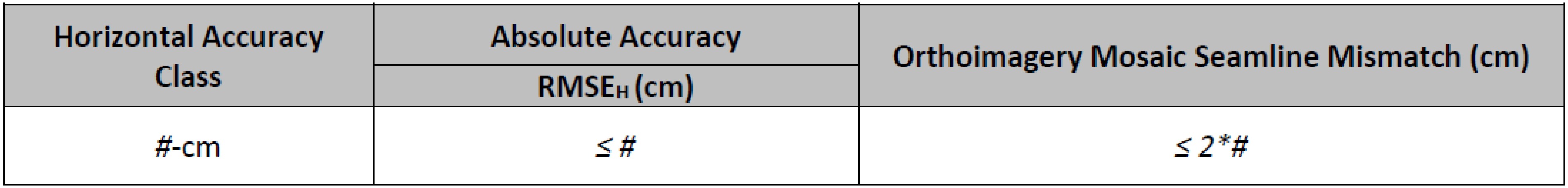
- Acceptable mean error may vary by project and should be negotiated between the data producer and the client.
  - As a rule, these Standards recommend that the mean error be less than 25% of the target RMSE specified for the project.

- When RMSE testing is performed, a discrepancy between the data set and a checkpoint that exceeds 3 times the target RMSE threshold in any component of the coordinate (X, Y, or Z) shall be interpreted as a blunder.

Horizontal Positional Accuracy Standard for Geospatial Data

Horizontal accuracy needs should be determined by project requirements, and the horizontal accuracy class of a data set should be expressed as a function of $RMSE_H$.

For example, a project's scope of work requires 7.5 cm Horizontal Accuracy Class, the $RMSE_H$ for the resulting data set must be ≤ 7.5 cm.



Horizontal Accuracy Class	Absolute Accuracy	Orthoimagery Mosaic Seamline Mismatch (cm)
	$RMSE_H$ (cm)	
#-cm	≤ #	≤ 2*#

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Vertical Positional Accuracy Standard for Elevation Data

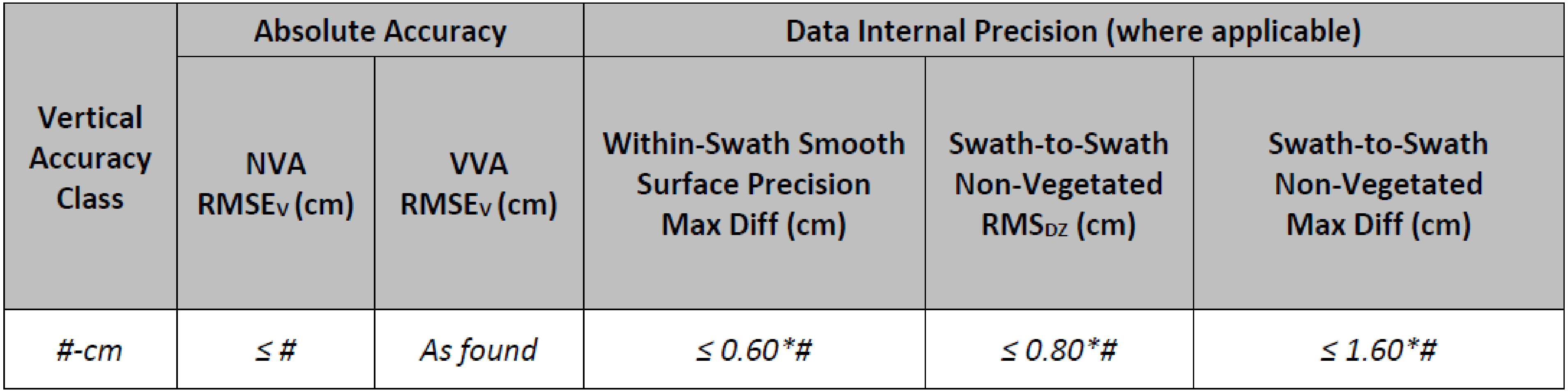
Vertical accuracy is to be expressed as $RMSE_V$ in both vegetated and non-vegetated terrain.

Vertical Accuracy Classes are defined by the associated $RMSE_V$ specified for the product.

$RMSE_V$ should be computed using both $RMSE_{V1}$ and $RMSE_{V2}$ error components.

While the Non-Vegetated Vertical Accuracy (NVA) must meet accuracy thresholds. The Vegetated Vertical Accuracy (VVA) has no pass/fail criteria and needs only to be tested and reported as found. If the NVA meets user specifications, VVA should be accepted at the reported accuracy level.

For projects where vegetated terrain is dominant, the data producer and the client may agree on an acceptable threshold.



Vertical Accuracy Class	Absolute Accuracy		Data Internal Precision (where applicable)		
	NVA RMSE$_V$ (cm)	VVA RMSE$_V$ (cm)	Within-Swath Smooth Surface Precision Max Diff (cm)	Swath-to-Swath Non-Vegetated RMS$_{DZ}$ (cm)	Swath-to-Swath Non-Vegetated Max Diff (cm)
#-cm	*≤ #*	*As found*	*≤ 0.60*#*	*≤ 0.80*#*	*≤ 1.60*#*

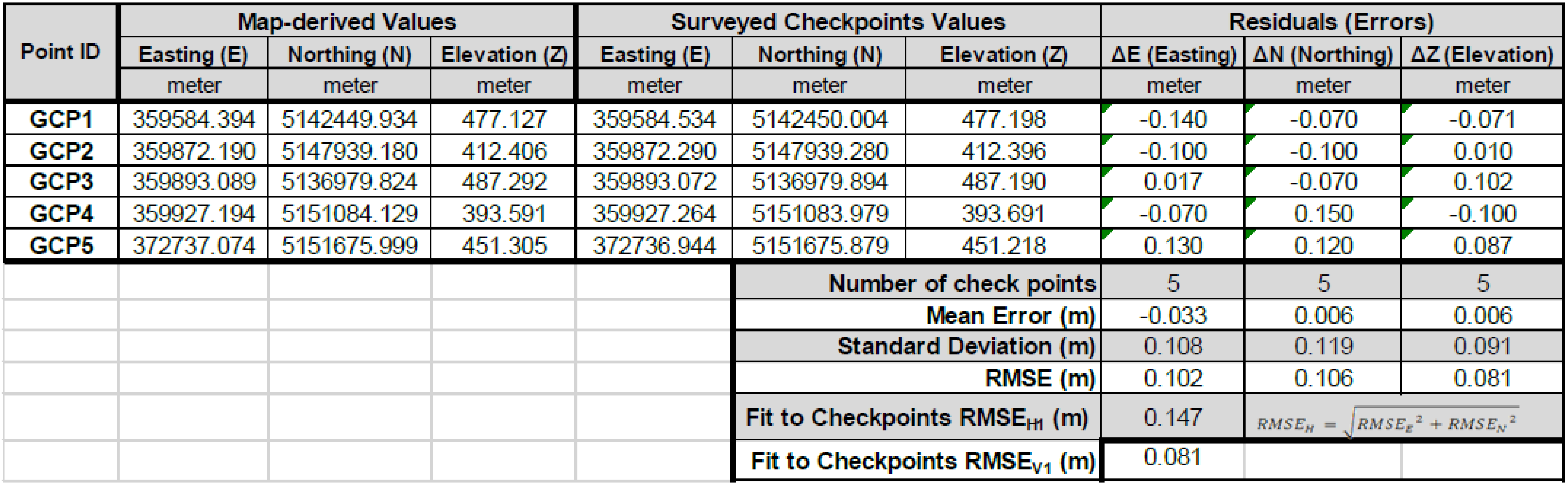
3D Positional Accuracy Standard for Geospatial Data

$RMSE_{3D}$ is derived from the horizontal and vertical components of error according to the following formula:

$$RMSE_{3D} = \sqrt{{RMSE_X}^2 + {RMSE_Y}^2 + {RMSE_Z}^2} \text{ or,}$$

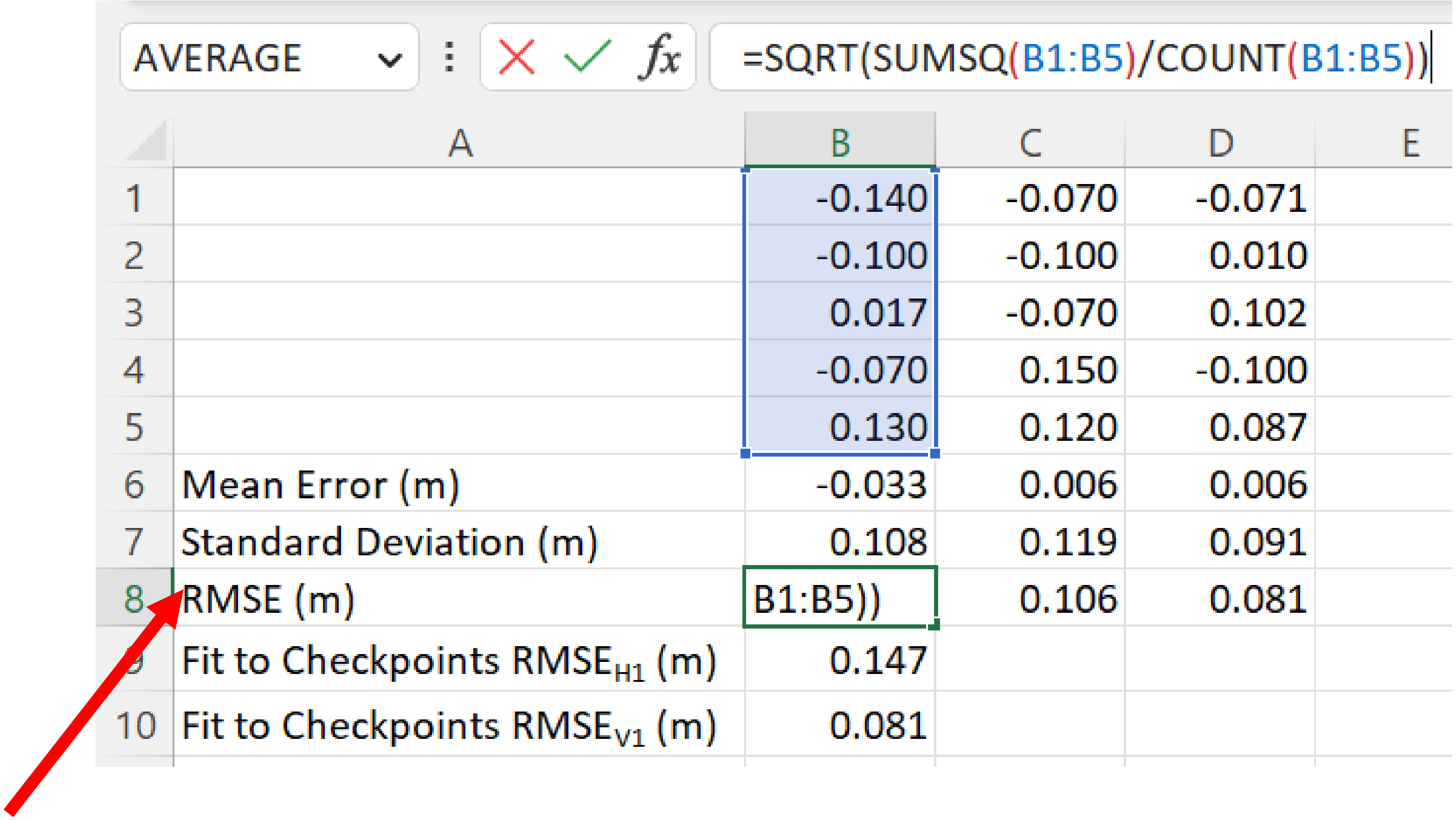
$$RMSE_{3D} = \sqrt{{RMSE_H}^2 + {RMSE_V}^2}$$

3D Accuracy Class	Absolute Accuracy
	$RMSE_{3D}$ (cm)
#-cm	≤ #



Point ID	Map-derived Values			Surveyed Checkpoints Values			Residuals (Errors)		
	Easting (E)	Northing (N)	Elevation (Z)	Easting (E)	Northing (N)	Elevation (Z)	ΔE (Easting)	ΔN (Northing)	ΔZ (Elevation)
	meter	meter	meter	meter	meter	meter	meter	meter	meter
GCP1	359584.394	5142449.934	477.127	359584.534	5142450.004	477.198	-0.140	-0.070	-0.071
GCP2	359872.190	5147939.180	412.406	359872.290	5147939.280	412.396	-0.100	-0.100	0.010
GCP3	359893.089	5136979.824	487.292	359893.072	5136979.894	487.190	0.017	-0.070	0.102
GCP4	359927.194	5151084.129	393.591	359927.264	5151083.979	393.691	-0.070	0.150	-0.100
GCP5	372737.074	5151675.999	451.305	372736.944	5151675.879	451.218	0.130	0.120	0.087
					Number of check points		5	5	5
					Mean Error (m)		-0.033	0.006	0.006
					Standard Deviation (m)		0.108	0.119	0.091
					RMSE (m)		0.102	0.106	0.081
					Fit to Checkpoints $RMSE_{H1}$ (m)		0.147	$RMSE_H = \sqrt{RMSE_E^2 + RMSE_N^2}$	
					Fit to Checkpoints $RMSE_{V1}$ (m)		0.081		

For the sake of brevity only five points are considered in this example; however, in reality thirty points must be used.



```
=SQRT(SUMSQ(B1:B5)/COUNT(B1:B5))
```

	A	B	C	D	E
1		-0.140	-0.070	-0.071	
2		-0.100	-0.100	0.010	
3		0.017	-0.070	0.102	
4		-0.070	0.150	-0.100	
5		0.130	0.120	0.087	
6	Mean Error (m)	-0.033	0.006	0.006	
7	Standard Deviation (m)	0.108	0.119	0.091	
8	RMSE (m)	B1:B5))	0.106	0.081	
9	Fit to Checkpoints RMSE$_{H1}$ (m)	0.147			
10	Fit to Checkpoints RMSE$_{V1}$ (m)	0.081			

Note that currently there is no RMSE function available in Excel.

Horizontal Accuracy of Elevation Data

Photogrammetric elevation data

For elevation data derived using stereo photogrammetry, apply the same Horizontal Accuracy Class that would be used for planimetric data or digital orthoimagery produced from the same source, based on the same photogrammetric adjustment.

Horizontal accuracies, either “produced to meet” or “tested to meet,” should be reported for all photogrammetrically derived elevation data sets, expressed as $RMSE_H$.

Lidar elevation data

Horizontal error in lidar-derived elevation data is largely a function of the following and can be estimated based on related parameters:

✓ Sensor positioning error as derived from GNSS

✓ Attitude (angular orientation) error as derived from the IMU

✓ Flying height above the mean terrain

Horizontal accuracy for a lidar-derived data set, $RMSE_H$:

$$RMSE_H = \sqrt{(GNSS\ positional\ error)^2 + \left(\frac{\tan(IMU\ roll\ or\ pitch\ error) + \tan(IMU\ heading\ error)}{1.478} * flying\ height\right)^2}$$

where flying height above mean terrain is in meters (m), GNSS positional errors are in centimeters (cm) and can be derived from published manufacturer specifications, and IMU errors are in angular units and can be derived from published manufacturer specifications.

Other error sources such as laser ranging and clock timing are small contributors to the error budget and can be considered negligible.

Low Confidence Areas in Elevation Data

In areas of dense vegetation, it can be difficult to collect reliable elevation data. This occurs in imagery where the ground is obscured or in deep shadow, or with lidar or radar imaging where there is poor signal penetration.

ASPRS Standards recommend that such low confidence areas be delineated by polygons and reported in the metadata.

Accuracy Requirements for Aerial Triangulation and IMU-Based Sensor Orientation

For photogrammetric data sets, the accuracy of **aerial triangulation and/or the GNSS/IMU-based direct georeferencing** must be higher than the accuracy of the derived products.

The accuracy of the aerial triangulation should be of the same order as the accuracy of the ground control used for the aerial triangulation.

For GNSS/IMU-based direct georeferencing, orientation accuracy shall be evaluated by comparing coordinates of checkpoints read from the imagery (using stereo photogrammetric measurements or other appropriate methods) to coordinates of the checkpoints as determined from higher-accuracy source data.

Aerial triangulation accuracies shall be evaluated using one of the following methods:

- Comparing coordinates of checkpoints computed in the aerial triangulation solution to coordinates of the checkpoints as determined from higher-accuracy source data.
- Comparing coordinates read from the imagery (using stereo photogrammetric measurements or other appropriate method) to coordinates of the checkpoints as determined from higher accuracy source data.

For projects providing deliverables that are only required to meet horizontal accuracy (orthoimagery or two-dimensional vector data), aerial triangulation errors in Z have a smaller impact on the horizontal error budget than errors in X and Y. In such cases, the aerial triangulation requirements for $RMSE_V$ can be relaxed. For this reason, these Standards recognize two different criteria for aerial triangulation accuracy:

- Aerial triangulation designed for digital planimetric data (orthoimagery and/or map) only:
  - $RMSE_{H_{1(AT)}} \leq ½ * RMSE_{H_{(MAP)}}$
  - $RMSE_{V_{1(AT)}} \leq RMSE_{H_{(MAP)}}$

- Aerial triangulation designed for projects that include elevation or 3D products, in addition to digital planimetric data (orthoimagery and/or map):
    - $RMSE_{H_{1(AT)}} \leq ½ * RMSE_{H_{(MAP)}}$
    - $RMSE_{V_{1(AT)}} \leq ½ * RMSE_{V_{(DEM)}}$

In the event aerial triangulation results do not meet the criteria stated above but do meet the RMSE requirements of the final product, attention should be shifted to the accuracy of the final products. If the final products meet target accuracies, an agreement to accept the aerial triangulation results should be made between the data producer and client. This should then be reported in the project metadata.

Accuracy Requirements for Ground Control Used for Aerial Triangulation

The accuracy of the ground control points should be twice the target accuracy of the final products, according to the following two categories:

- Ground control for aerial triangulation designed for digital planimetric data (orthoimagery and/or map) only:
  - ○ $RMSE_{H(GCP)} \leq ½ * RMSE_{H(MAP)}$
  - ○ $RMSE_{V(GCP)} \leq RMSE_{H(MAP)}$

- Ground control for aerial triangulation designed for projects that include elevation or 3D products, in addition to digital planimetric data (orthoimagery and/or map):
  - $\mathrm{RMSE}_{H(\mathbf{GCP})} \leq ½ * \mathrm{RMSE}_{V(\mathbf{MAP})}$
  - $\mathrm{RMSE}_{V(\mathbf{GCP})} \leq ½ * \mathrm{RMSE}_{V(\mathbf{DEM})}$

Accuracy Requirements for Ground Control Used for Lidar

The vertical accuracy of the ground control points used for lidar calibration and boresighting should be twice the target accuracy of the final products. Similarly, ground checkpoints used to assess lidar data accuracy should be twice the target accuracy of the final products.

- $RMSE_{V_{(GCP)}} \leq ½ * RMSE_{V_{(DEM)}}$

Similar guidelines can be followed for other digital data acquisition technologies, such as IFSAR.

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Positional Accuracy Assessment of Geospatial Data Products

Assessment of product accuracy requires a network of checkpoints that is well distributed throughout the project area. This network should have higher positional accuracy than the product being tested.

First Component of Positional Error – Product Fit to Checkpoints

For each checkpoint, the surveyed coordinates should be compared to the coordinates derived from the tested product. Then, the discrepancies between the two sets of coordinates should be computed and tabulated.

RMSE should be computed in each dimension from all the individual computed discrepancies between the product and the checkpoints or control points in that dimension, as stated in the following formula:

$$RMSE_X = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x_{i(map)} - x_{i(surveyed)}\right)^2}$$

$$RMSE_Y = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(y_{i(map)} - y_{i(surveyed)}\right)^2}$$

$$RMSE_Z = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(z_{i(map)} - z_{i(surveyed)}\right)^2}$$

The first component of horizontal error is:

$$RMSE_{H_1} = \sqrt{{RMSE_X}^2 + {RMSE_Y}^2}$$

The first component of vertical error is:

$$RMSE_{V_1} = RMSE_Z$$

The first component of three-dimensional error is:

$$RMSE_{3D_1} = \sqrt{{RMSE_X}^2 + {RMSE_Y}^2 + {RMSE_Z}^2}$$

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Second Component of Positional Error – Survey Control and Checkpoint Error

The second component of positional error is the error of the survey of the control points and checkpoints. Because these Standards have relaxed the requirement for survey point accuracy to two times the target product accuracy, as well as the high accuracy expected from the products, these errors can no longer be considered negligible.

The second component of positional error is represented as $RMSE_{H2}$, $RMSE_{V2}$, or $RMSE_{3D2}$, and it is the quantity reported by the field surveyor.

Horizontal Positional Accuracy

To compute the horizontal accuracy of a two-dimensional product, such as a planimetric map or orthorectified image, the height component of the survey point error is ignored. We assume that X (Easting) and Y (Northing) survey point errors are equal; that is, $RMSE_{X2} = RMSE_{Y2}$.

$$Horizontal\ Product\ Accuracy\ (RMSE_H) = \sqrt{{RMSE_{H_1}}^2 + {RMSE_{H_2}}^2}$$

Example

At the end of the analyses, $RMSE_{H1}$ was found to be 0.051 m by using the following the formula:

$$RMSE_{H_1} = \sqrt{RMSE_x{}^2 + RMSE_y{}^2}$$

Additionally, checkpoint report stated that the field survey was conducted using an RTK-GPS-based technique to an accuracy of 0.019 m.

The final horizontal accuracy is computed as

$$RMSE_H = \sqrt{RMSE_{H_1}{}^2 + RMSE_{H_2}{}^2} = \sqrt{(0.051)^2 + (0.019)^2} = 0.054$$

Vertical Positional Accuracy

Vertical product accuracy is computed from the first and second components of vertical error:

$$Vertical\ Product\ Accuracy\ (RMSE_V) = \sqrt{{RMSE_{V_1}}^2 + {RMSE_{V_2}}^2}$$

Example

When the checkpoints were used to verify the vertical accuracy of the lidar data, the fit of the lidar data to the checkpoints was found to be $\mathrm{RMSE}_{V1} = 1$ cm.

The survey report states that the RTK techniques produced checkpoints with $\mathrm{RMSE}_{V2} = 2$ cm.

$$\text{Vertical product accuracy} = \sqrt{1^2 + 2^2} = 2.24$$

As can be seen the correct vertical accuracy of the lidar dataset with respect to the vertical datum is 2.24 cm, rather than the commonly reported value of 1 cm.

Three-dimensional Positional Accuracy

The three-dimensional product accuracy is computed from the vertical and horizontal product accuracy:

$$RMSE_{3D} = \sqrt{{RMSE_H}^2 + {RMSE_V}^2}$$

Checkpoint Accuracy and Placement

Checkpoints used for product accuracy assessment shall be at least two times more accurate than the required accuracy of the geospatial product being evaluated.

This shall hold true for survey checkpoints, as well as checkpoints derived from other geospatial data products.

To avoid a biased accuracy assessment, a checkpoint should be located away from any ground control points used in the initial processing and data calibration.

Horizontal checkpoints shall be established at well-defined points. A well-defined point is a feature for which the horizontal position can be

1) placed with a high degree of certainty in the product being tested, and

2) measured to the required degree of accuracy with respect to the geodetic datum.

Well-defined points must be easily visible or identifiable on the tested product and on the ground.

In the case of orthorectified imagery, when rectifying the imagery, well-defined points shall not be selected on features that are above the elevation surface.

For example, the corner of a building rooftop should not be used as a horizontal checkpoint in imagery that was orthorectified using a bare-earth DEM; however, if the imagery was orthorectified using a 3D model that includes buildings, then a point on a building rooftop may be an acceptable horizontal checkpoint.

Checkpoints used for vertical accuracy assessment shall be established at locations that minimize interpolation errors when comparing the product elevation surface to the elevations of the checkpoints.

These checkpoints shall be surveyed in open terrain that is flat or in areas of gentle and uniform slope and it should not be placed near vertical artifacts or abrupt changes in elevation (preferably 3 meters or more away).

Checkpoints used for vertical accuracy assessment are not required to meet the above requirements of well-defined points.

Checkpoint Density and Distribution

Checkpoints for accuracy assessment should be well distributed around the project area.

Considerations made for challenging circumstances—such as rugged terrain, water bodies, heavy vegetation, and inaccessibility—are acceptable if agreed upon between the data producer and the client.

In no case shall the assessment of planimetric accuracy of digital orthoimagery be based on fewer than thirty (30) checkpoints. Similarly, the assessment of the NVA or VVA of elevation data should be based on no fewer than thirty (30) checkpoints each.

If either horizontal or vertical accuracy is assessed using fewer than thirty (30) checkpoints, a special reporting statement should be included and outlined. This is generally the case with UAV surveys because setting 30 checkpoints is not practical.

Data Internal Precision (Relative Accuracy) of Lidar and IFSAR Data

Data internal precision assesses the internal geometric integrity of an elevation data set, without regard to survey control or absolute coordinates. These assessments can reveal potential systematic errors related to sensor stability, quality of GNSS trajectories, ranging precision, calibration of sensor models, and/or boresight alignment.

Assessment of data internal precision includes two aspects of data quality: within-swath (smooth-surface) precision, and swath-to-swath precision.

Requirements for data internal precision are more stringent than requirements for absolute accuracy.

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Wherever the following assessment methods refer to raster surfaces created from lidar data, the raster cell size should be twice the Nominal Pulse Spacing (NPS) of the lidar point cloud.

Assessment of within-swath and swath-to-swath precision should be performed from these raster surfaces, using test areas in open, uniformly-sloping terrain that contain only single-return lidar points determined to be valid surface returns.

Within-Swath (Smooth-Surface) Precision

Within-swath precision is usually only associated with lidar collections and is a measure of the precision of the system when detecting flat, hard surfaces.

Within-swath internal precision is an indicator of ranging precision and sensor stability.

Within-swath internal precision may be evaluated in single-swath data by creating two raster elevation surfaces—one from the minimum point elevation in each raster cell, and the other from the maximum point elevation in each raster cell. The two surfaces are differenced, and the maximum difference is compared to acceptable thresholds for each accuracy class.

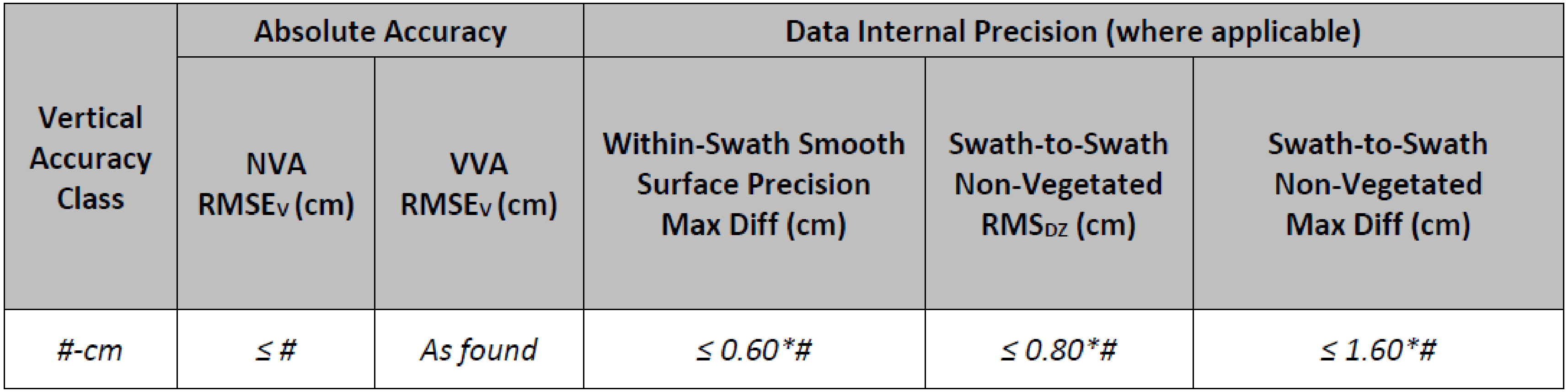
Another method used to evaluate within-swath precision is to create two raster elevation surfaces—one using points with encoded scan direction flag = 0, and the other using points with encoded scan direction flag = 1. The two surfaces are then subtracted from each other to obtain the difference.

There are no recommended quantitative thresholds, but this method of assessment can be helpful in revealing systematic errors in the data stemming from a hardware malfunction or a poorly-calibrated sensor model.

Swath-to-Swath Precision

Swath-to-swath precision for both lidar and IFSAR collections is measured in areas of open terrain within the swath overlap.

The first method of computing swath-to-swath precision is to create a surface from each of the overlapping swaths. An elevation is extracted from each surface at a number of point sample locations, then an elevation difference is calculated for each sample point. A root-mean-square difference, RMS_{DZ}, is then calculated from all the sample differences and compared to the threshold values presented once again in the below table.



Vertical Accuracy Class	Absolute Accuracy		Data Internal Precision (where applicable)		
	NVA $RMSE_V$ (cm)	VVA $RMSE_V$ (cm)	Within-Swath Smooth Surface Precision Max Diff (cm)	Swath-to-Swath Non-Vegetated RMS_{DZ} (cm)	Swath-to-Swath Non-Vegetated Max Diff (cm)
#-cm	*≤ #*	*As found*	*≤ 0.60*#*	*≤ 0.80*#*	*≤ 1.60*#*

A second method of computing swath-to-swath precision is to create two raster elevation surfaces, one from each swath. The two surfaces are differenced, and an RMS_{DZ} calculated using sample areas that are in open terrain. This approach results in a more comprehensive assessment, and also provides the user with a visual representation of the swath-to-swath differences.

Accuracy Reporting

Horizontal, vertical, and three-dimensional positional accuracies shall be assessed and formally reported according to their appropriate accuracy class.

In addition to accuracy class, related statistical quantities should be computed and reported, including:

- Residual errors at each checkpoint
- Maximum error
- Minimum error
- Mean error
- Median error
- Standard deviation
- RMSE

Concluding Remarks

ASPRS Accuracy Standards 2023 have become more aligned with science and statistical theory.

These Standards are intended to be a living document which can be updated in future editions to reflect changing technologies and user needs.

THANK YOU FOR YOUR ATTENTION